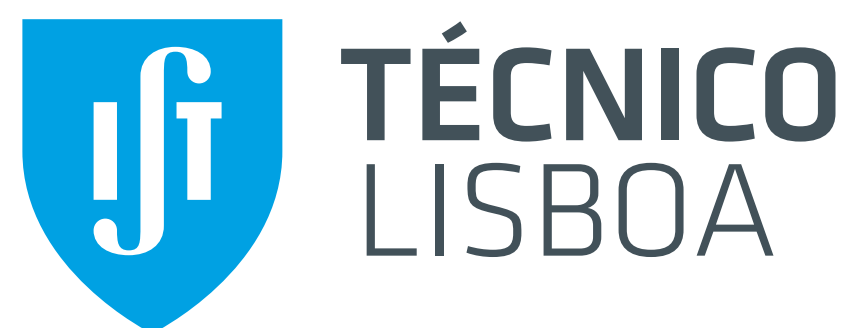


Supercomputação encontra plasmas extremos

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Work in collaboration with:

IST: T. Grismayer, B. Martinez, O. Amaro, B. Barbosa, R. Babjak, R. A. Fonseca, L. O. Silva

ELI: M. Jirka, O. Klimo, G. Korn, S. Weber

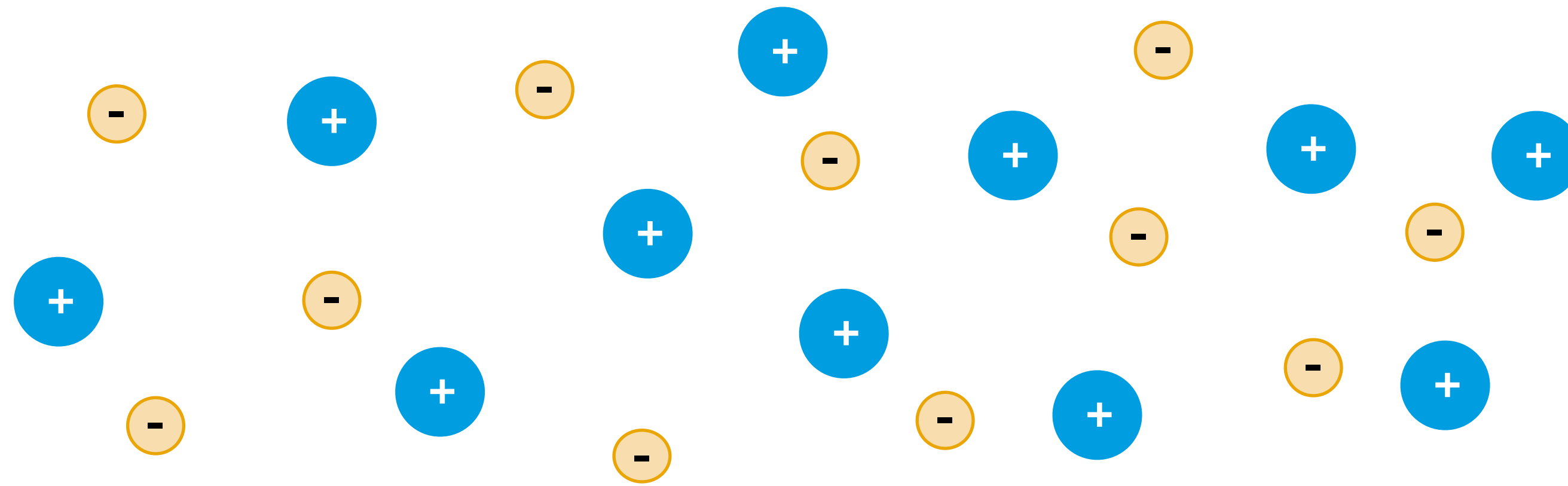
Simulation results obtained at Jugene/Juqueen, SuperMUC, Jaguar, Fermi/Marconi, Salomon, MareNostrum.



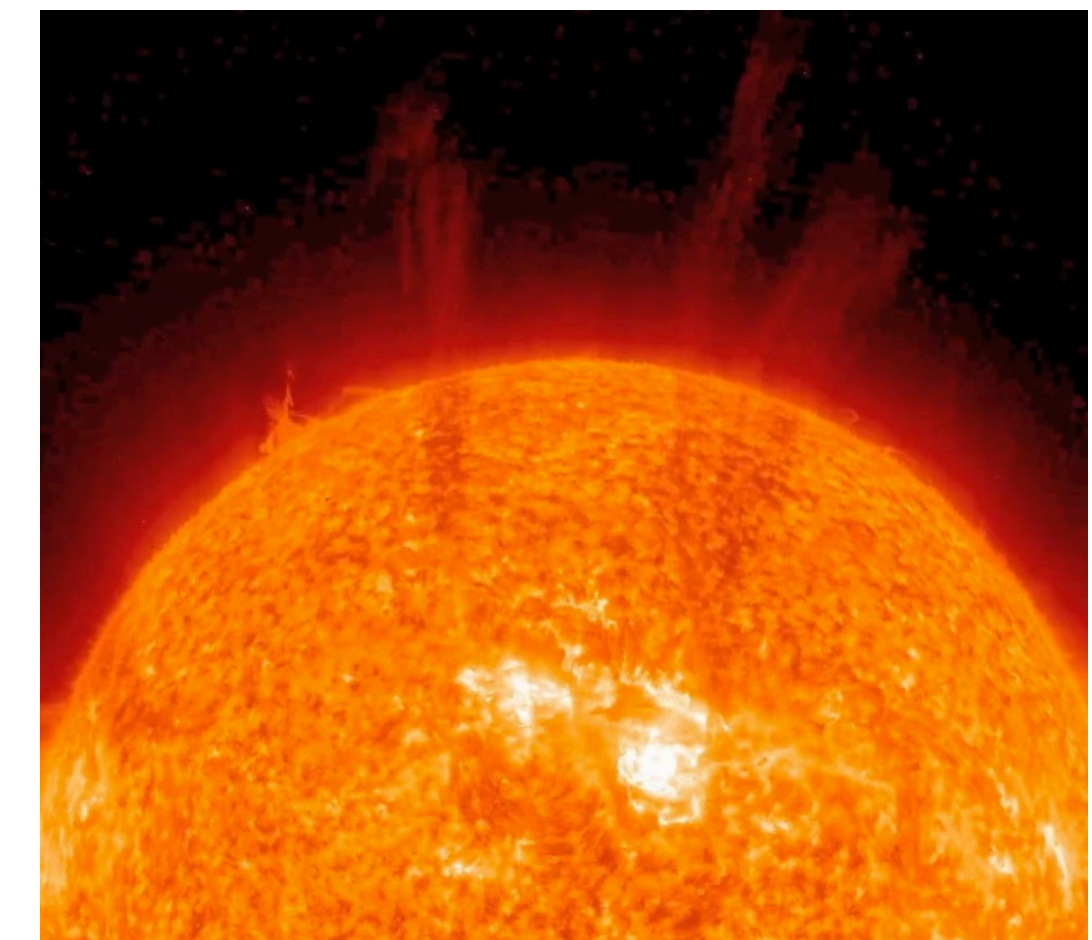
Supported by the
Seventh Framework
Programme of the
European Union



What is a plasma?

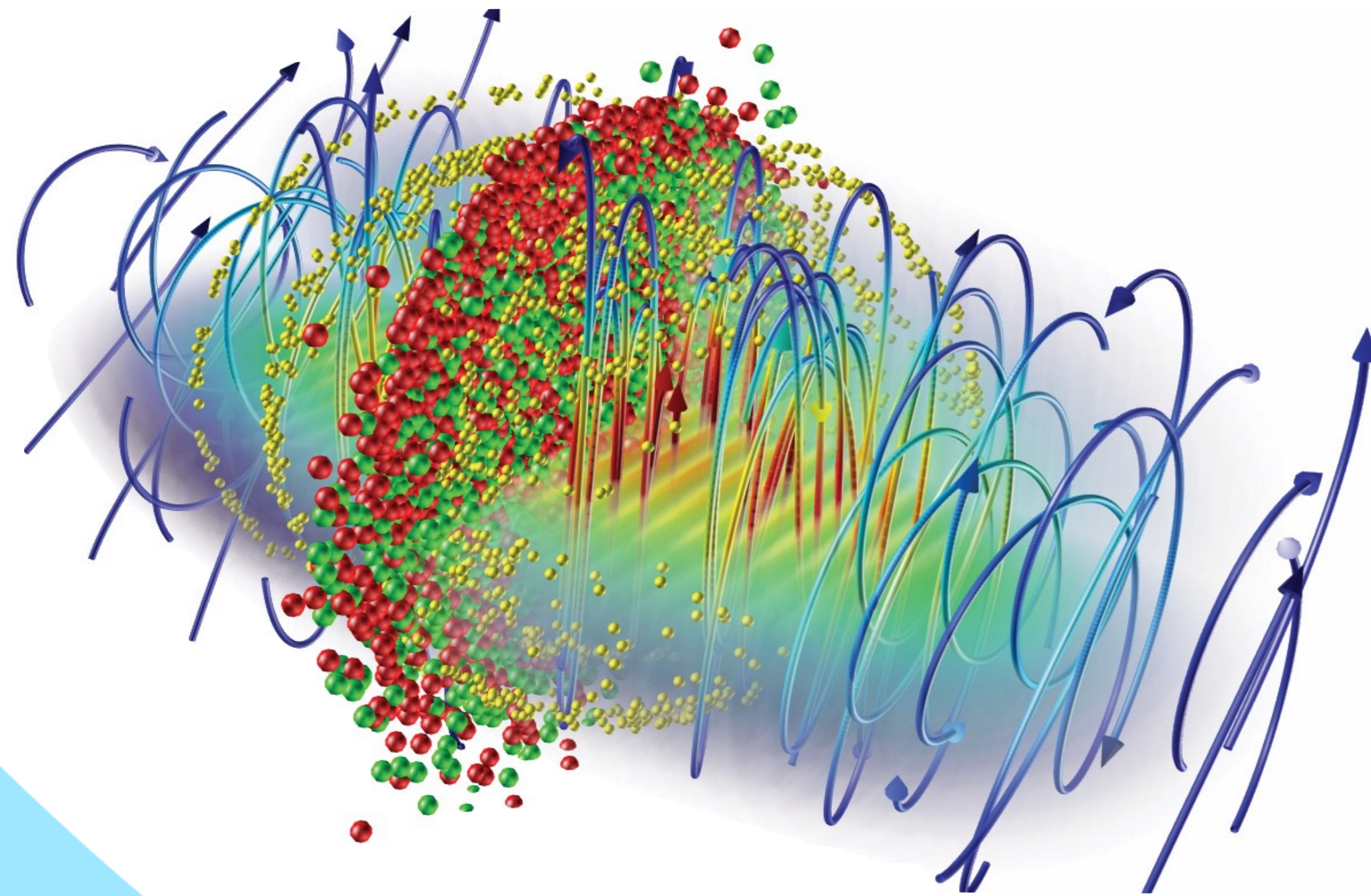


4th state of matter



- ▶ Plasma is a quasi-neutral ionised gas formed by an approximately equal number of electrons and ions
- ▶ Over 99% of the visible Universe is in the plasma state
- ▶ Most (or all) molecular bonds are broken
- ▶ In a way, plasma is an “already destroyed” material
- ▶ This allows strong fields to exist in plasmas - the fields that would destroy any other material

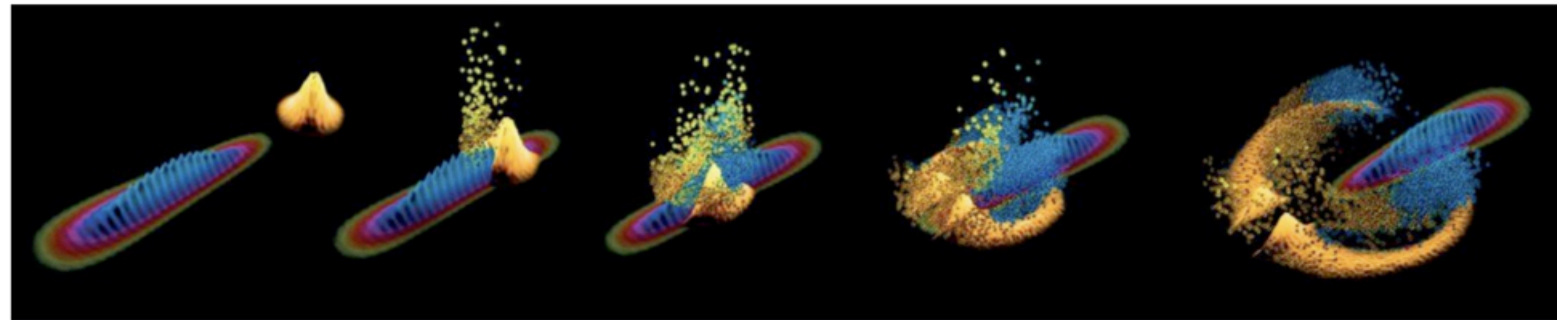
What happens in a plasma in the presence of extreme fields?



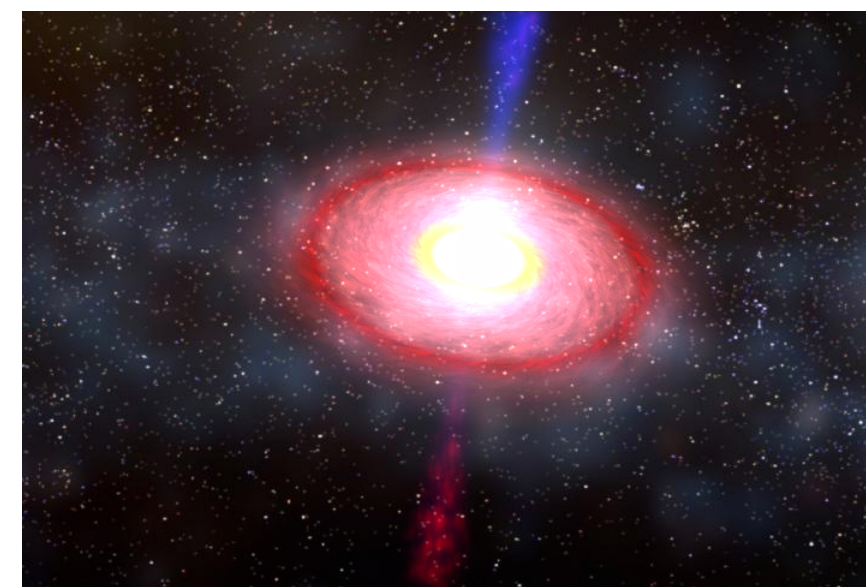
- ▶ relativistic particles
- ▶ radiation reaction
- ▶ hard photon emission
- ▶ (anomalous) radiative trapping
- ▶ e+e- pair production
- ▶ QED cascades
- ▶ EM field depletion by self-created plasma

In nature, where can such plasmas be found?

When intense lasers interact with matter



In magnetospheres of neutron stars



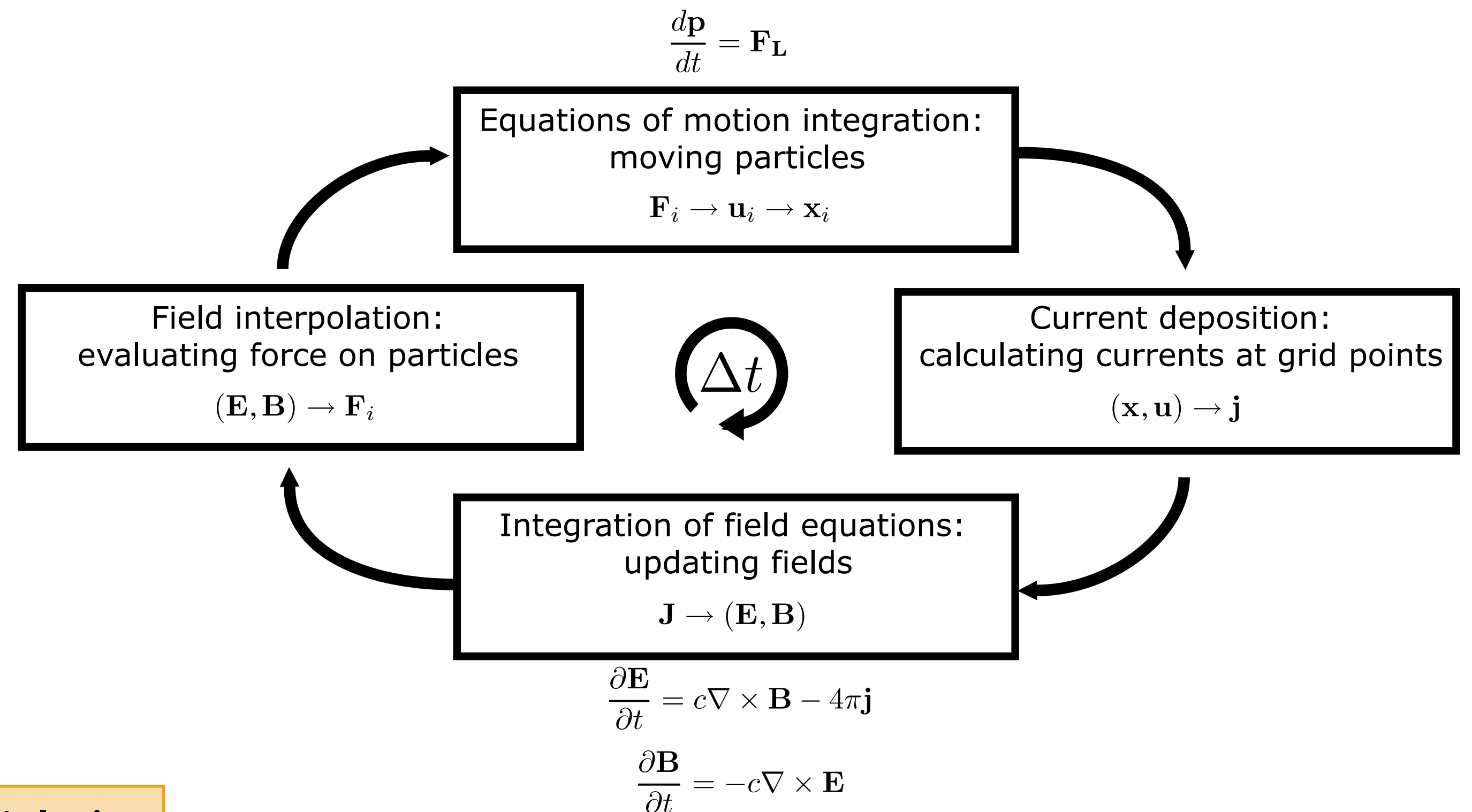
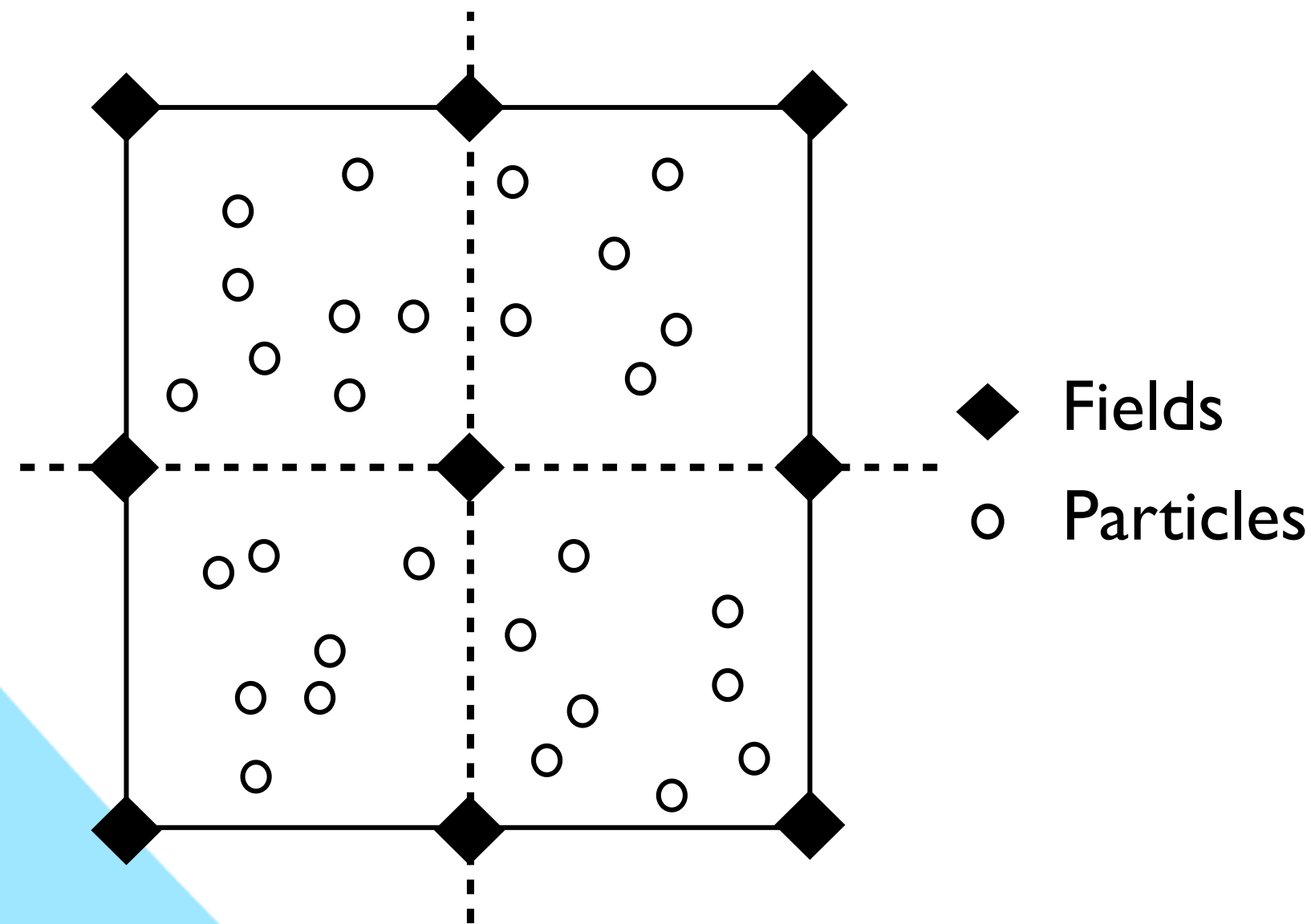
Around black holes



Credit: Dana Berry / NASA

Credit: Event Horizon Telescope collaboration, M87 / NASA

Particle-in-cell algorithm captures how EM fields affect moving charges, as well as how currents affect the EM background



PIC simulates plasma interactions from first principles!



Committed to open science

Open-access model

- 40+ research groups worldwide are using OSIRIS
- 300+ publications in leading scientific journals
- Large developer and user community
- Detailed documentation and sample inputs files available

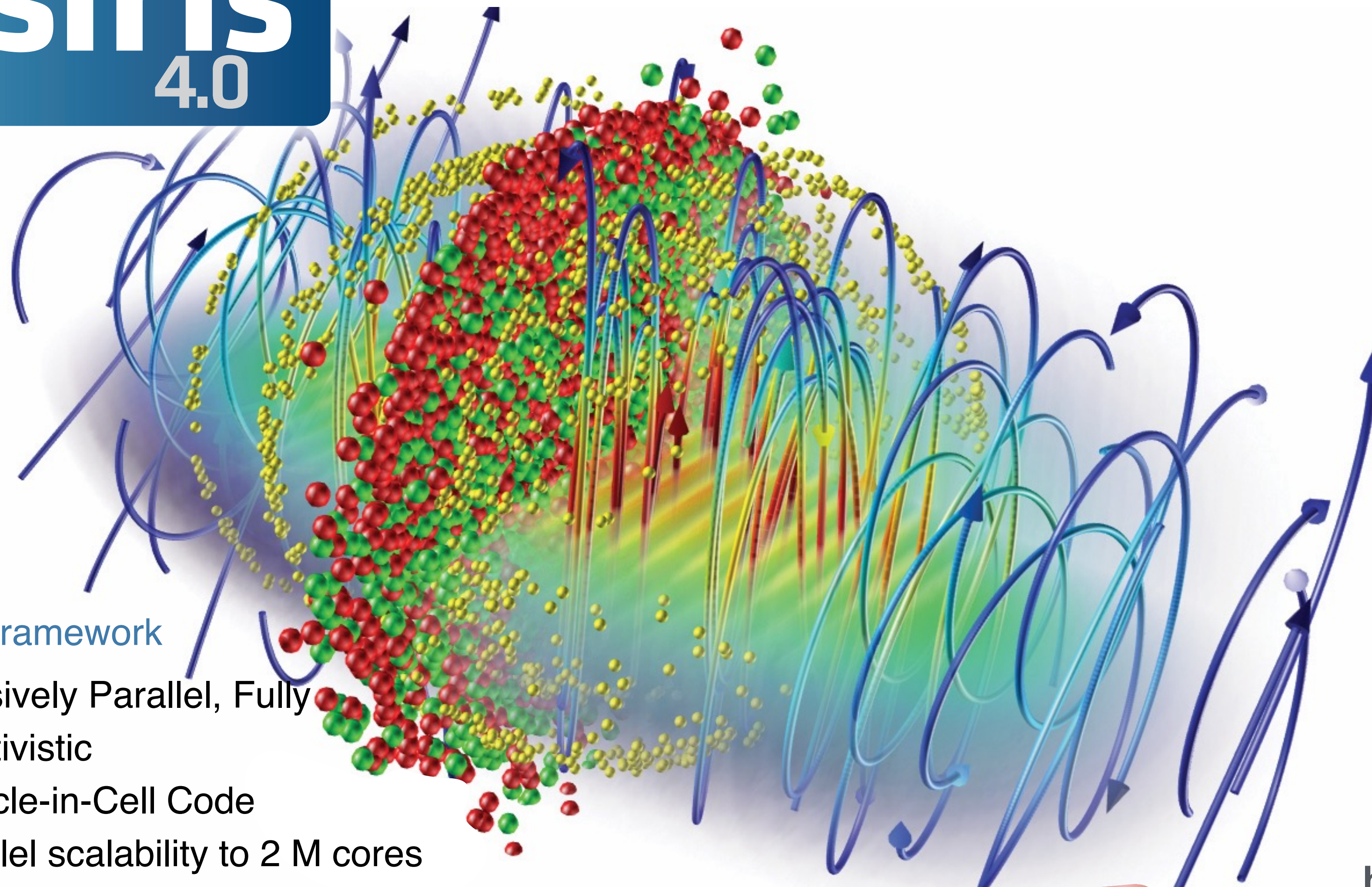
Using OSIRIS 4.0

- The code can be used freely by research institutions after signing an MoU
- Find out more at:

<http://epp.tecnico.ulisboa.pt/osiris>

OSIRIS framework

- Massively Parallel, Fully Relativistic Particle-in-Cell Code
- Parallel scalability to 2 M cores
- Explicit SSE / AVX / QPX / Xeon Phi / CUDA support
- Extended physics/simulation models



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The ZPIC educational code suite

- **ZPIC code suite**

- Open-source PIC code suit for plasma physics education
- Fully relativistic 1D and 2D EM-PIC algorithm
- Electrostatic 1D/2D PIC algorithm

- **Requirements**

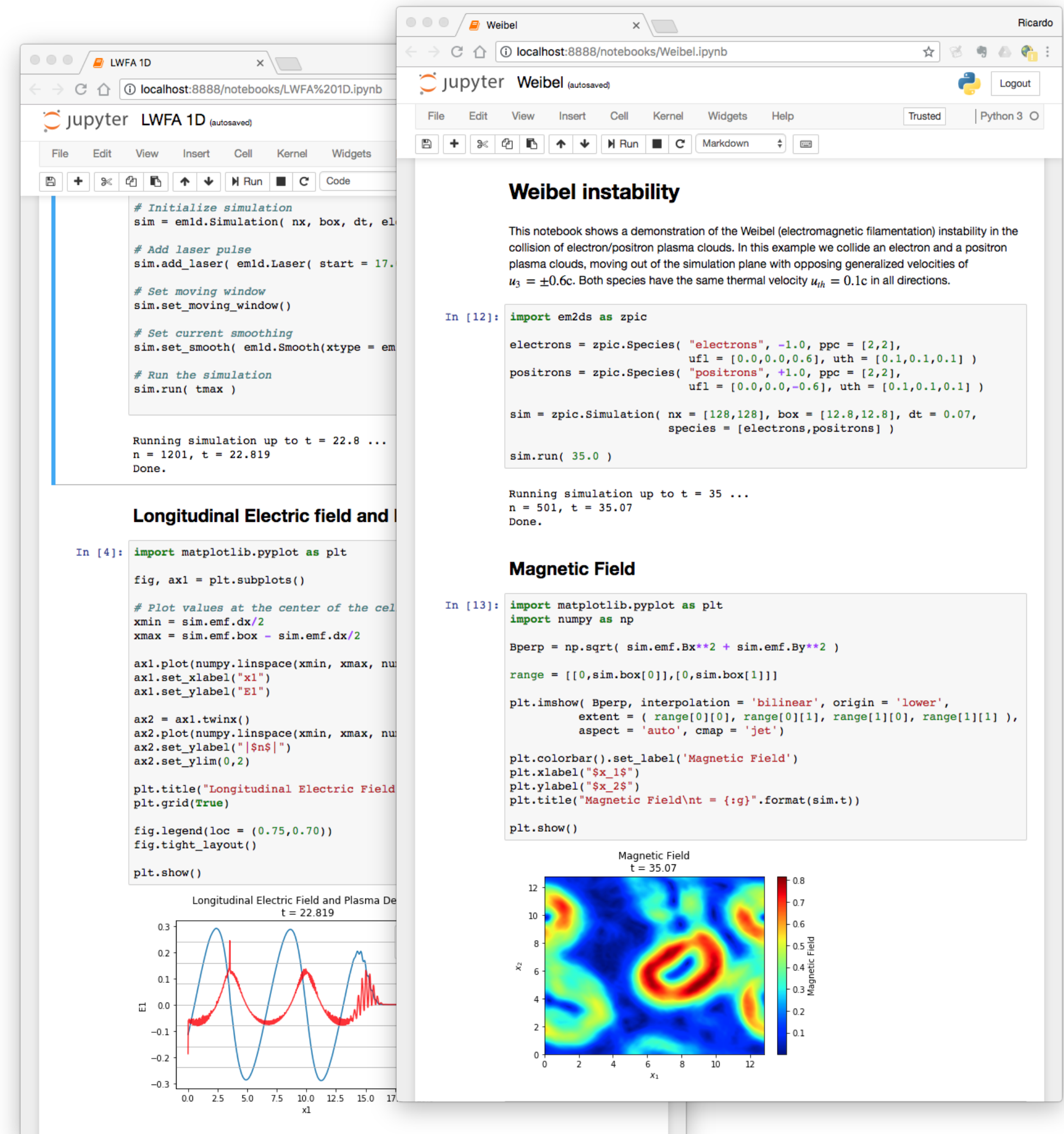
- No external dependencies for base code, requires only C99 compiler
- Python interface included

- **Jupyter Notebooks**

- Includes set of Python notebooks with example problems
- Detailed explanations of code use and physics

- **Also available through Docker**

- If you just want to run the notebooks you can use a Docker image available on DockerHub: **zamb/zpic**

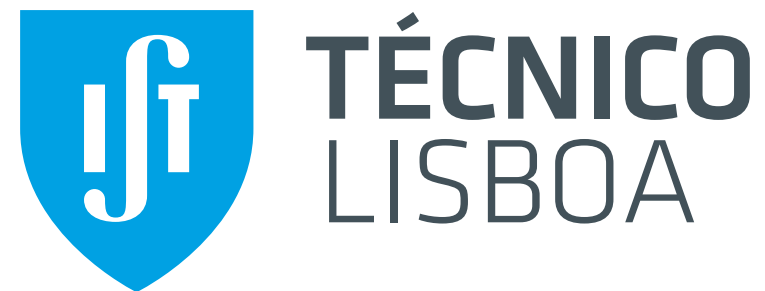


zpic@edu



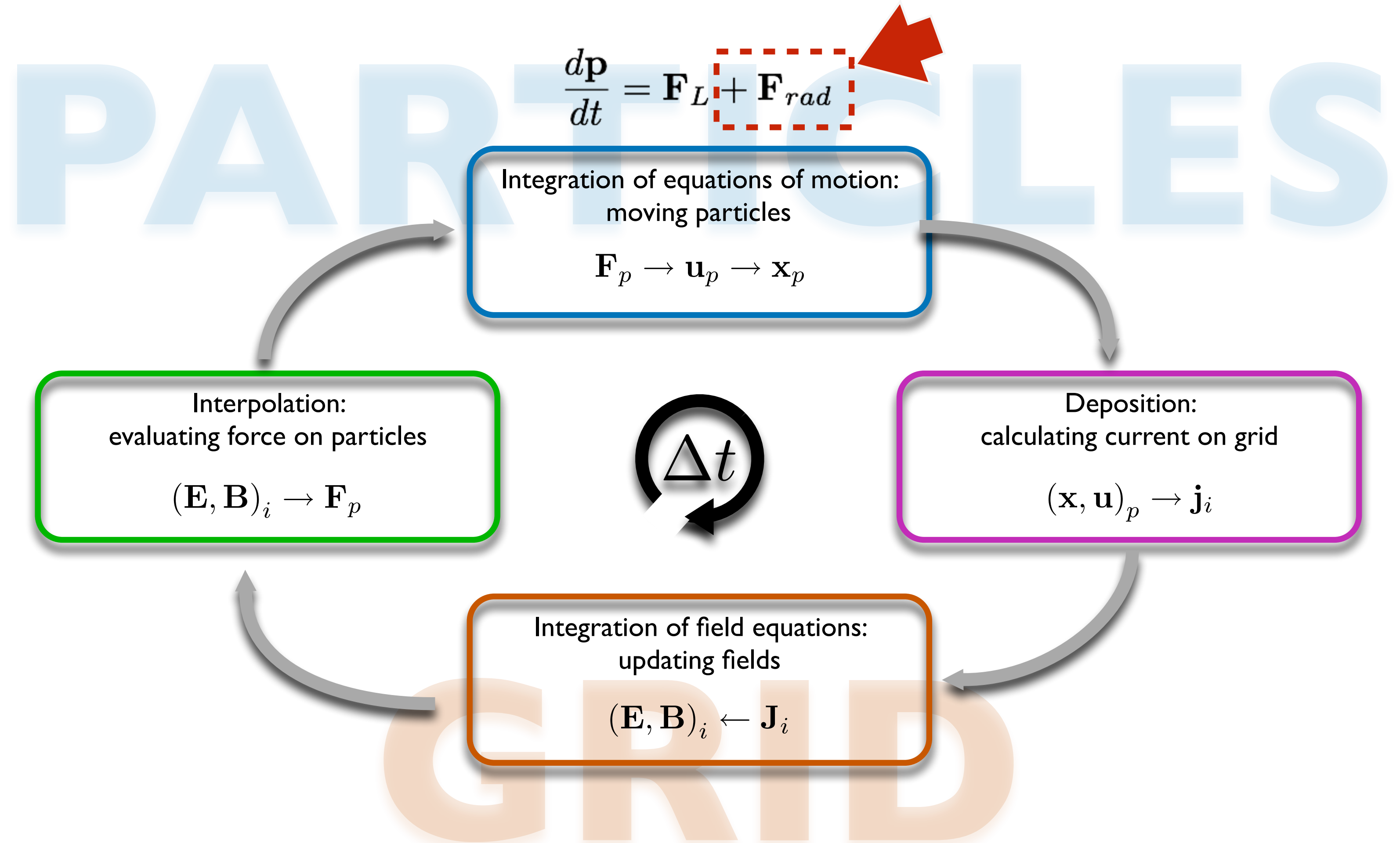
Come find us on GitHub
github.com/ricardo-fonseca/zpic

Classical radiation reaction can be added like a “damping force” in the particle pusher*



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M.Vranic et al., CPC 204, 141-157 (2016)



What new features are needed in plasma modelling?

Adding classical radiation reaction

- ▶ Modelling electron beam slowdown in scattering configurations
- ▶ Modelling other configurations where only a fraction of electrons may be subject to RR but where this can alter qualitative behaviour

M.Vranic et al., PRL (2014); M.Vranic et al., CPC (2016); M.Vranic et al, PPCF (2018)

Performance improvements

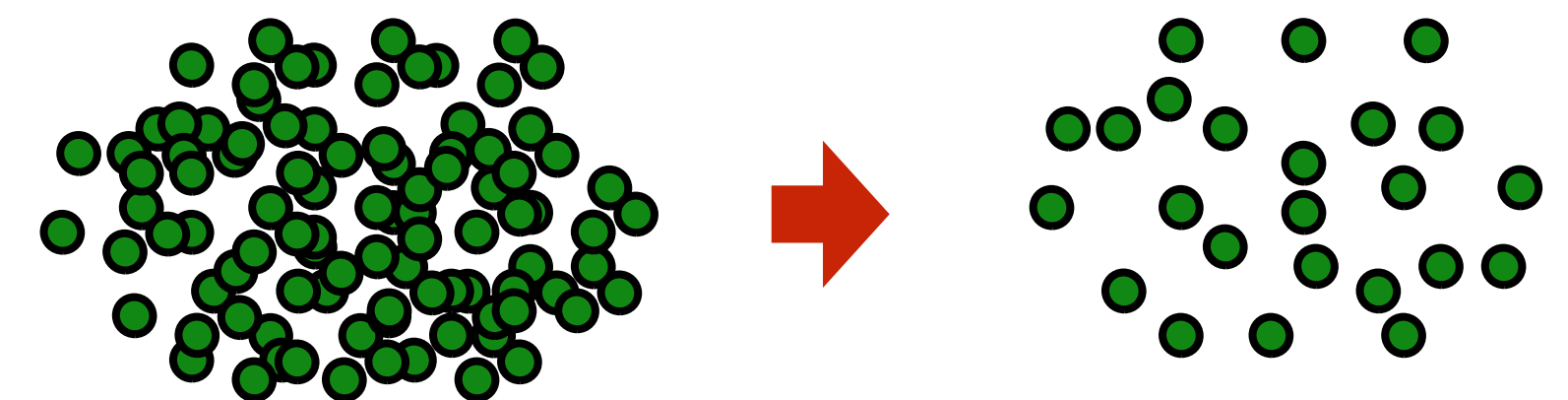
- ▶ Particle merging, advanced load balancing schemes
- ▶ Essential for all the projects with strong QED effects

M.Vranic et al., CPC (2015)

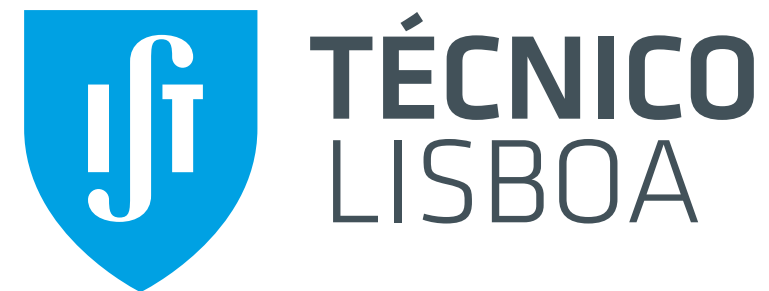
Adding quantum processes

- ▶ Modelling the onset of QED, RR from quantum perspective
- ▶ Modelling e^+e^- pair production
- ▶ QED cascades, nonlinear regimes where many particles are created and collective plasma dynamics can alter the background fields

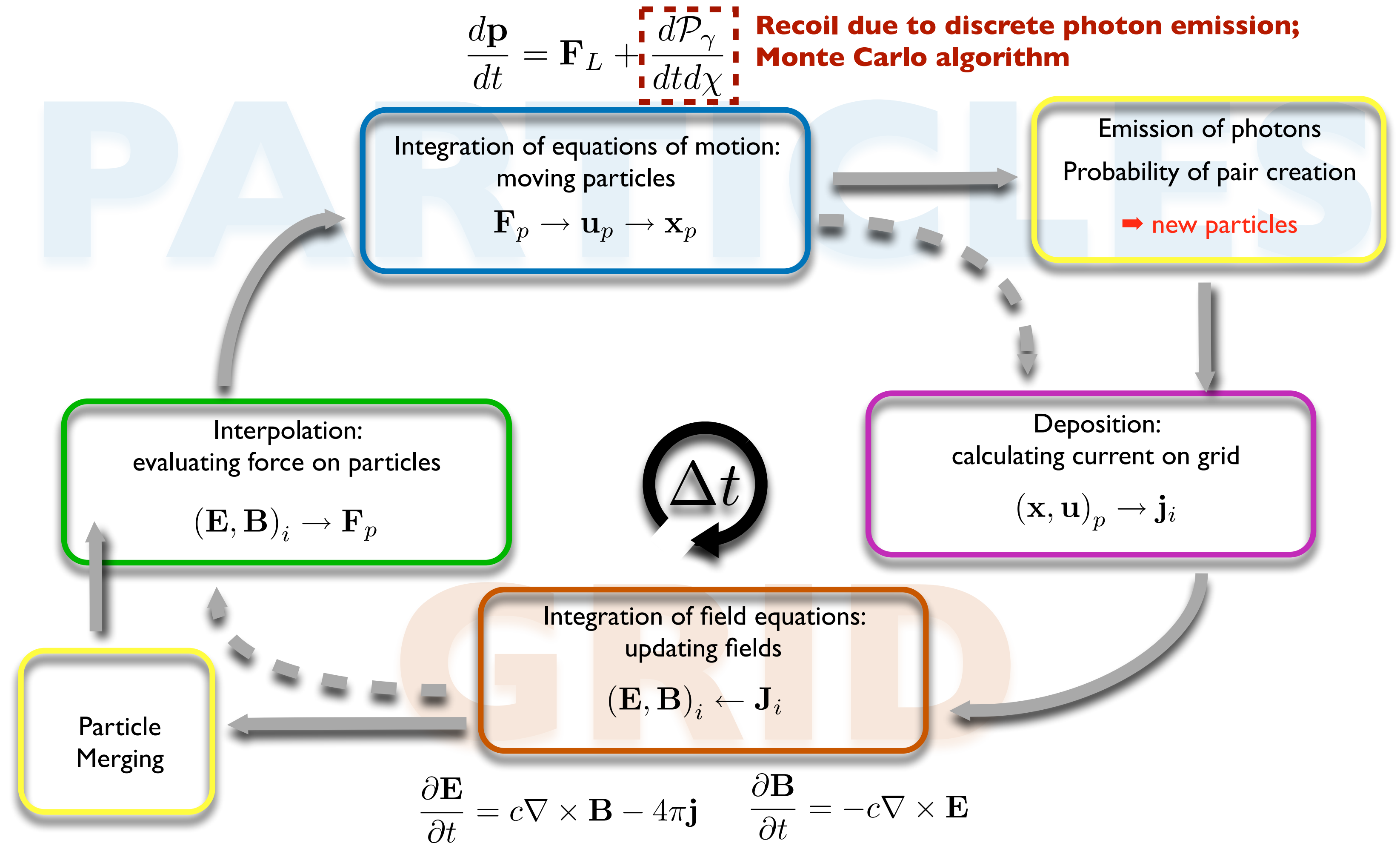
M.Vranic et al, NJP (2016); T. Grismayer et al, POP (2016); T. Grismayer et al, PRE (2017);
J. L. Martins et al, PPCF (2016); M.Vranic et al, PPCF (2017); M.Vranic et al, SciRep (2018);



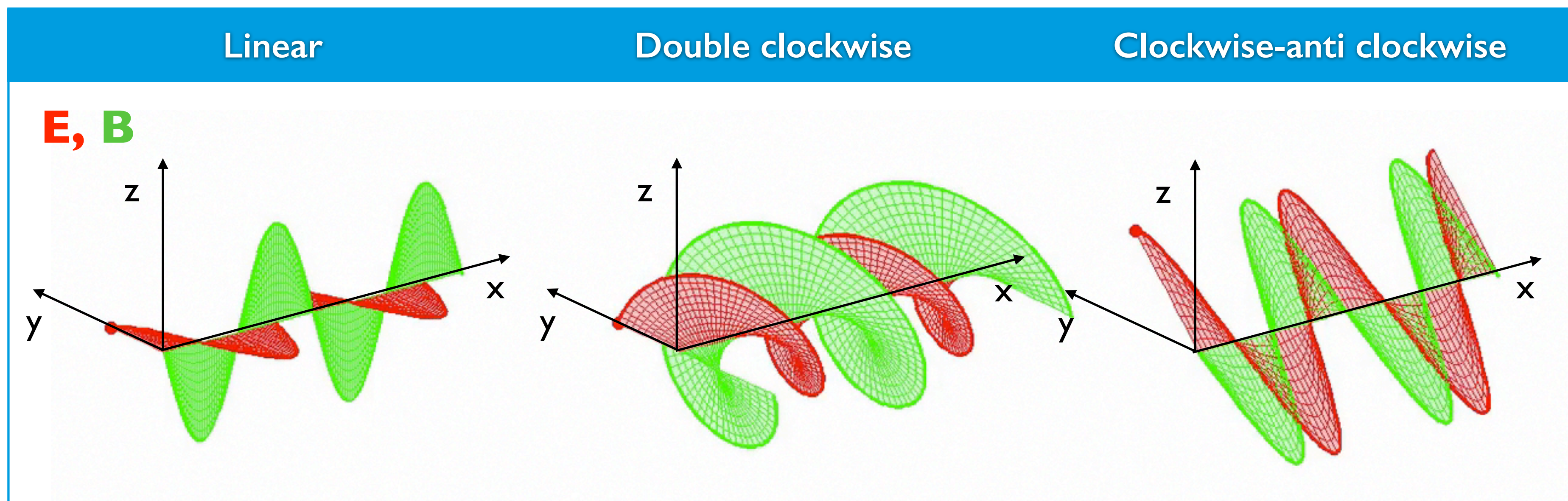
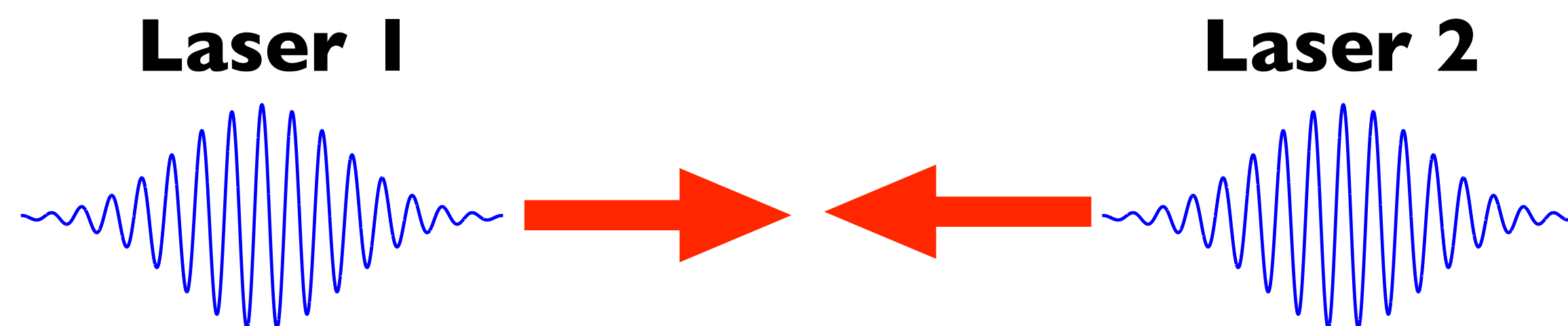
Quantum processes need to be included via Monte Carlo



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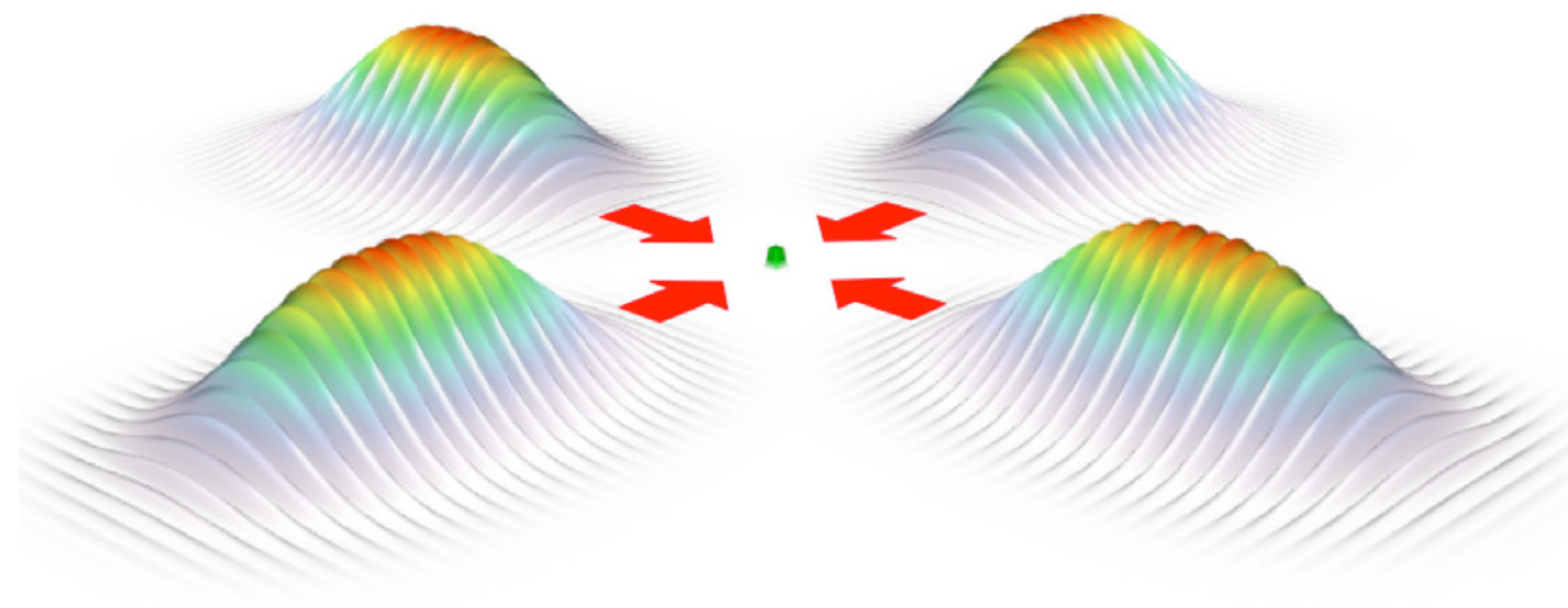


Standing wave (2-laser) configurations for QED cascades

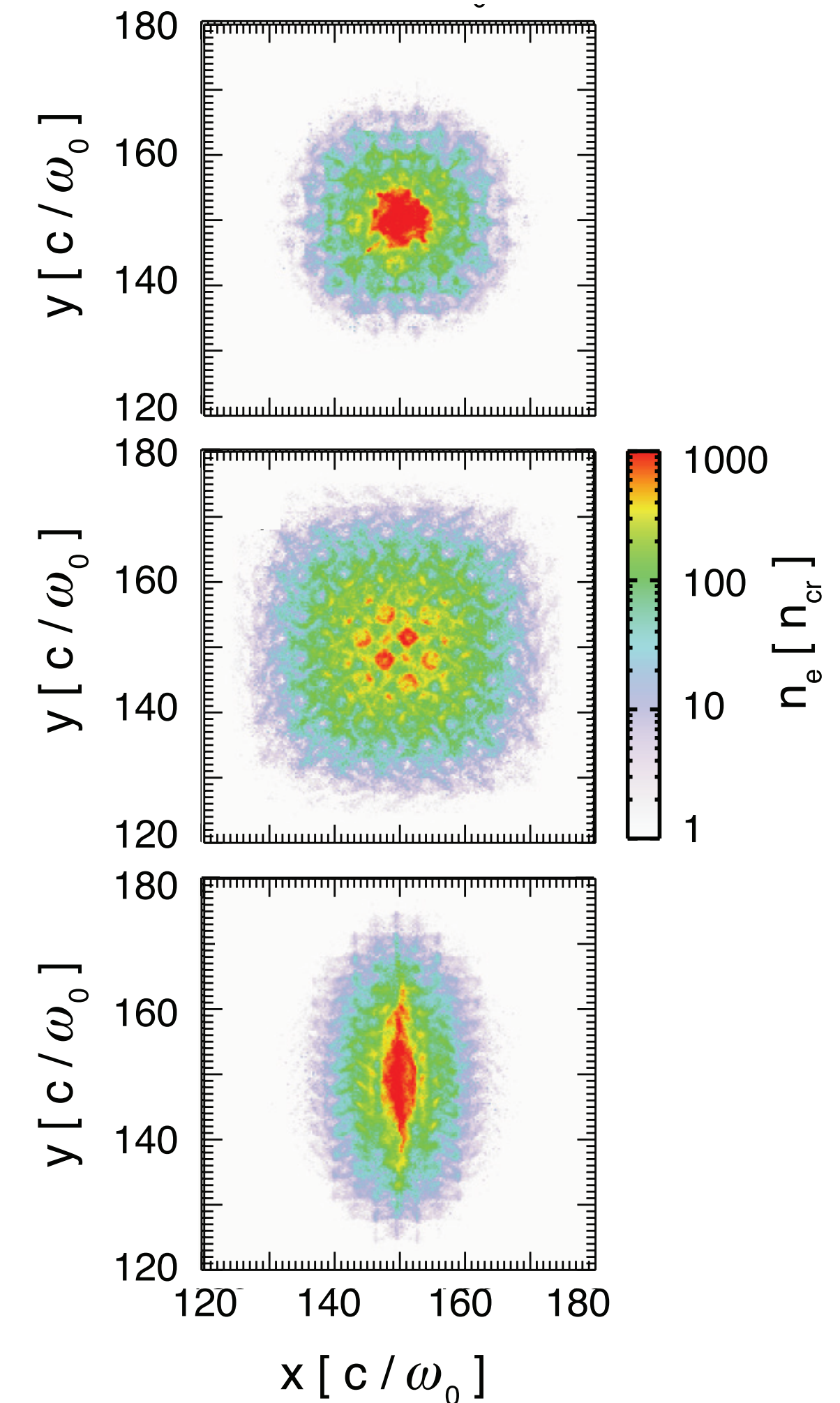
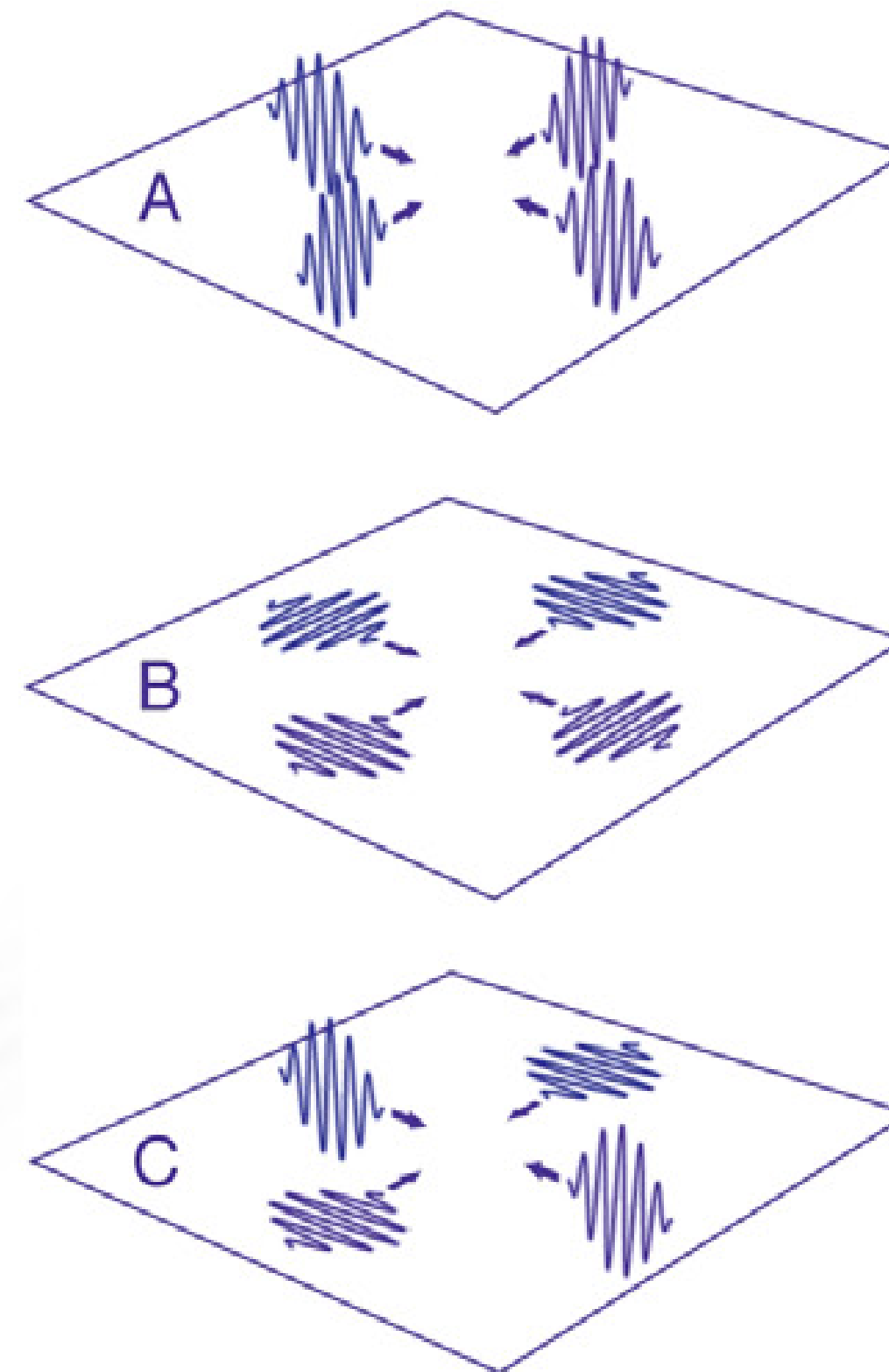


A.R Bell and J. G Kirk PRL, 101, 200403 (2008); M.A Fedotov et al. PRL 105, 080402 (2010); E. Nerush et al., 106 035201, PRL (2011); T. Grismayer et al., POP 23, 056706 (2016)

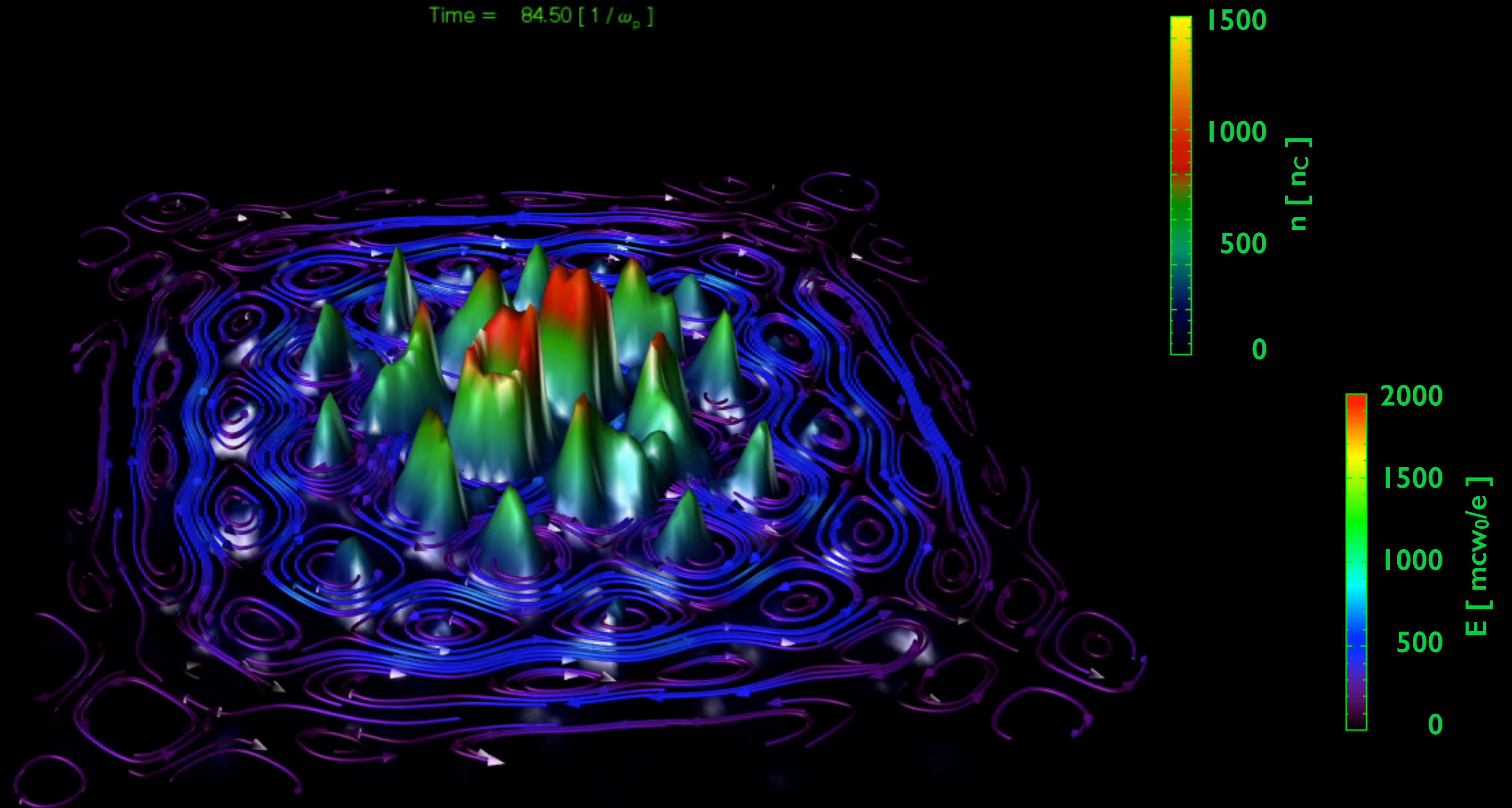
We can create a 2D standing wave using multiple lasers



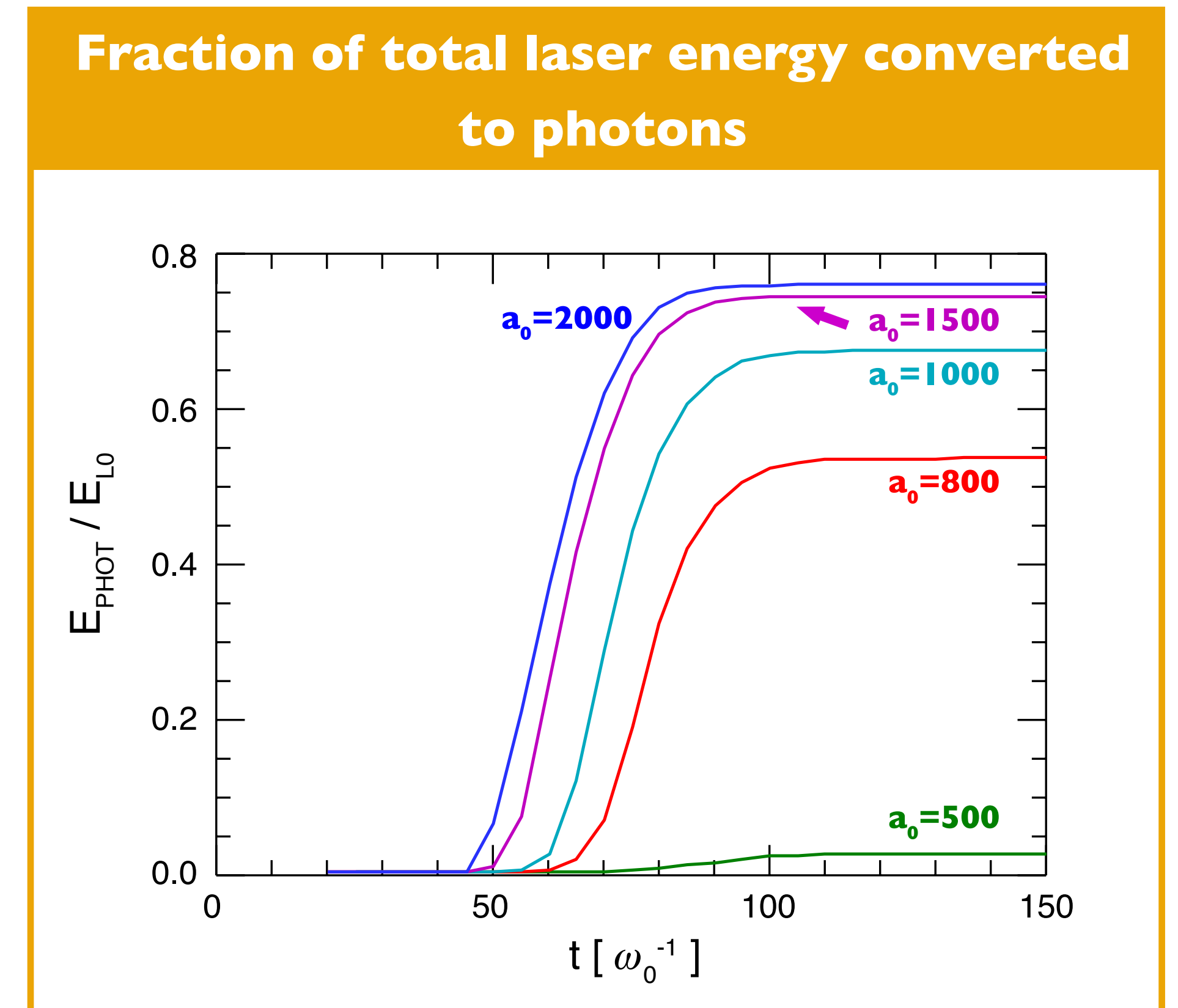
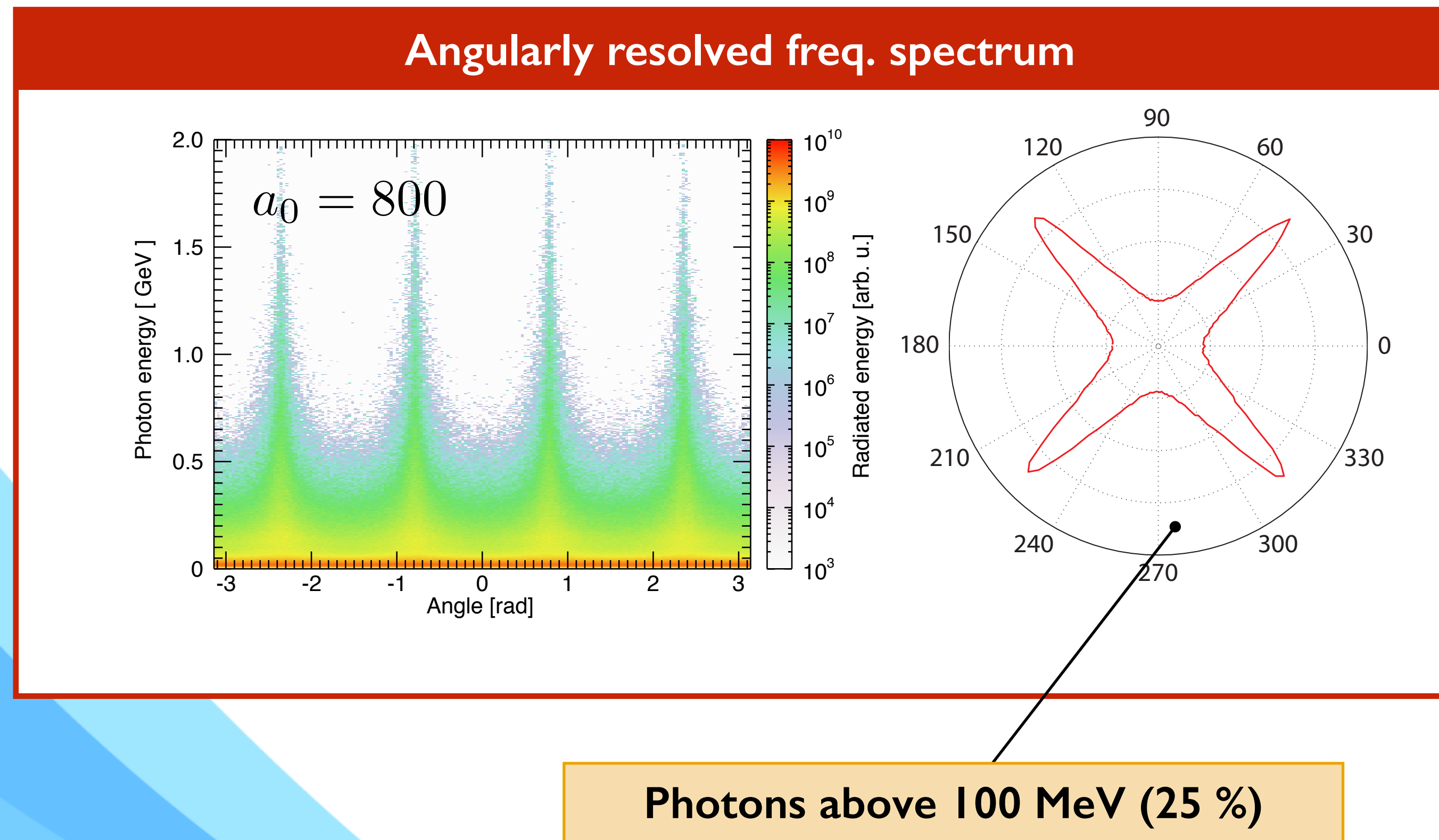
M. Vranic et al.,
PPCF 59, 014040 (2017)



Enough plasma is produced to disrupt the 2D standing wave



Laser energy is efficiently converted to new particles and hard photons



These simulations require HPC systems

- ▶ Over 1 million core-hours per simulation
- ▶ Without designated performance enhancements, the simulations would not be possible even on large HPC systems
- ▶ PI & co-PI on competitive supercomputing projects with ~ 300 million core-hours combined



MareNostrum, BSC



Ada King, Countess of Lovelace